NASA TECHNICAL TRANSLATION NASA TT F-15,915

THE SIGNIFICANCE OF BIOLOGICAL FACTORS IN THE WEATHERING OF ROCKS AND MINERALS

P. V. Ivashov

(NASA-TT-F-15915) THE SIGNIFICANCE OF BIOLOGICAL FACTORS IN THE WEATHERING OF ROCKS AND MINERALS (Scientific Translation Service) 34 p HC $4.75 CSCL 08G
N74-31872
Unclas
G3/13 47777

Translation of "Znacheniye biologicheskikh faktorov v vyvetrivanii porod i mineralov", In: Biogeokhimiya Zony Gipergenesza (Biogeochemistry of the Hypergenesis Zone), Edited by A. S. Khomentovskiy, Moscow, "Nauka" Press, 1971, pp. 30-50.

RECEIVED NASA STI FACILITY INPUT BRANCH SEP 1974

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 SEPTEMBER 1974

STANDARD TITLE PAGE

1. Report No. NASA TT F-15,915	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle THE SIGNIFICANCE OF BIOLOGICAL FACTORS IN THE WEATHERING OF ROCKS AND MINERALS		5. Report Date September, 1974
		6. Performing Organization Code
7. Author(s) P. V. Ivashov		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108		11. Contract or Grant No. NASw-2483
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Znacheniye biologicheskikh faktorov v vyvetrivanii porod i mineralov", In: Biogeokhimiya Zony Gipergenesza (Biogeochemistry of the Hypergenesis Zone), Edited by A. S. Khomentovskiy, Moscow, "Nauka" Press, 1971, pp. 30-50.

16. Abstract

The role of biological factors in the weathering of rocks and minerals is discussed. Based on the data presented, it is concluded that biological factors play an extremely important role.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	32	

THE SIGNIFICANCE OF BIOLOGICAL FACTORS IN THE WEATHERING OF ROCKS AND MINERALS

P. V. Ivashov

According to current thought, the term "weathering" means the complicated heterogeneous process by which rocks and minerals, formed in the depths of the earth's crust under certain thermodynamic conditions, for a number of reasons appear on the surface or in surface layers of the earth's crust, i.e., in a different thermodynamic situation and are, therefore, subjected to destruction. Weathering is the disintegration and transformation of primary native matrix — igneous, metamorphic and sedimentary rock — due to the joint action of physical, chemical and biological (biogeochemical) processes. /30*

Although the essence of physical (Chernyakhovskiy, 1966, 1968) and especially chemical (Keller, 1963) factors of weathering are now more or less known and understood, the effect of biological factors on the weathering of rocks and minerals has received very little investigation. However, it cannot be said that modern literature, geological-geochemical or pedological-biological, has failed to note biological factors taking part in the disintegration of rock. There are indications, but the essence and, especially, the systematization of these factors, universally distributed in nature, are not revealed. For example, some authors still reduce the biological factors of weathering basically to a mechanical effect of plant roots on the mineral substratum.

We in no way are pretending that this report is a complete and exhaustive explanation of the role of biological factors in the weathering of rocks and minerals. This is an extremely complex problem and requires special methodological analysis by specialists — geobotanists, soil scientists, microbiologists, geologists, geochemists, biogeochemists, etc. By this report we would

*Numbers in the margin indicate pagination of original foreign text.

only like to stimulate an interest in this question and take a small step toward the systematization of some factors of biological weathering.

V. I. Vernadskiy (1940) pointed out that "to study processes of weathering of rock only from the point of view of physico-chemical phenomena is to show the backwardness of this branch of chemical geology. The weathering of rock is a biologically inert process and the study of this process must be approached biogeochemically." /31

The exceptionally important role of the organic world as a whole in the evolution of inorganic matter in surface layers of the earth's crust or in the zone of hypergenesis was indicated in their time by Yu. A. Ravich-Shcherbo (1928), K. D. Glinka (1931), A. G. Vologdin (1947), N. A. Krasil'nikov (1949a, b), M. A. Glazovskaya (1950, 1952), I. N. Yaroslavtsev (1952), V. L. Omelyanskiy (1953), B. B. Polynov (1956), I. I. Ginzburg (1952), I. I. Ginzburg et al., (1963) and many other researchers.

It must be kept in mind that physical and chemical as well as biological factors of weathering act simultaneously, supplement each other and are always interconnected. Therefore, the process of weathering under the effect of particular factors must not be considered in isolation, i.e., for example, we must not speak of biogeochemical weathering without taking into account the effect of other weathering agents. B. B. Polynov (1945) in his time emphasized this: "We must avoid the idea of sterile weathering. The mechanical and chemical effects of weathering can and should be distinguished, but it is hardly correct to differentiate mechanical, chemical and organic processes. It can be stated that in nature there is no isolated mechanical weathering, unconnected with chemical change, and all the more the reverse phenomenon. The existence of sterile weathering is doubtful even for a desert" (Polynov, 1945, p. 338).

In some cases the effect of a number of biological weathering factors on the mineral substratum is of a purely chemical nature, for example: the effect of discharges of plant roots, the effect of humus acids of soils, etc. But as the initial cause of these processes is biogenic, they must also be considered as biological factors of weathering (Ivashov, 1965).

The biological sciences — geobotany, soil science, microbiology, biochemistry and others, as well as the science of a geochemical nature — biogeochemistry — have now accumulated much factual material indicating that biological factors play an extremely essential role in the disintegration of rocks and minerals and in some cases — even the determining or main role. The range of effect of biological weathering factors is very wide. Certain factors of biological weathering, especially microorganisms, exist in all topographical-climate zones of the earth (Tauson, 1948).

The weathering of rocks and minerals under the effect of biological factors must be considered not only as disintegration of the mineral substratum to ultimate, simpler products, but also as a synthesis of secondary formations at the expense of the primary mineral. Such an approach to these processes is /32
completely necessary for proper understanding of the evolution of a mineral in the zone of hypergenesis under the effect of biogenic factors.

According to the character of life processes of the organic world on our planet (plants, animals, microorganisms), in the first approximation two large groups of biological weathering factors can be distinguished: 1) a group of biological weathering factors developing during life processes of plant organisms (higher plants and lithophytic flora); 2) a group of biological weathering factors developing during the life processes of microorganisms and some lower animals, for example: earthworms, termites, etc. In fact, closely associated to these two groups is a third group of biological weathering factors developing during the life processes of man in his creation of cultural landscapes on the surface of the earth. However, we shall not consider these factors in this report as their effect on weathering and the evolution of minerals in the zone of hypergenesis is extremely complex and their consideration requires special methodological analysis. Among factors of biological weathering developing during the life processes of plants we must note the following.

1. The adaptation of plant associations to certain complexes of rocks and minerals. The effect of this factor is revealed as a whole in the more intense effect of plants on a particular mineral substratum where they grow without visible signs of depression or different kinds of pathological changes, while these same plants, growing on a different mineral substratum, show clear signs of depression. Undoubtedly, in the first case the plants will be more viable, they will have a well-developed root system and, therefore, in their life cycle their effect on the mineral substratum will be much more intense than in the second case. As V. S. Viktorov (1955) notes, the greatest harmony of this adaptation of plants to certain complexes of rock depends on their ecological characteristics.

It must be kept in mind that the existence of such harmony in the mineral substratum-plant system requires favorable physico-geographical conditions, primarily, climate. This phenomenon was perhaps first indicated by A. N. Krasnov (1888): "Climate, responsible for the general character of processes of change in rocks, is also responsible for the general character of vegetation. Neither chemical composition nor physical properties, under different climate conditions...can cause the same vegetation" (p. 15).

L. N. Tyulina (1928) in her geobotanical observations also noted that "rock emerges as the main factor in the distribution of vegetation in all details only within the limits of the same climate zone" (page 2). /33

Harmonic adaptation of plant associations to certain complexes of rocks in the same topological-climate zone is responsible for the favorable development of a most important natural process — soil formation or the formation of the present weathered crust.

It must be noted that adaptation to certain rocks and minerals is also typical of lithophytic flora — lichens, a form of symbiotic existence of two organisms — fungi and algae (Krasil'nikov, 1956).

N. A. Krasil'nikov (1949b) points out that lichens are distributed on the surface of rock masses, as a rule, not in a solid layer, but in spots and foci, the nature of which is related to the quality of the rock. For example, basalts become covered with lichens more than tufas, i.e., there is a selective ratio of lithophytic flora due to the specifics of individual centers of rock. Evidently, differences in the physico-chemical properties of individual sections of rock, particularly their nutritiousness for lithophytic flora, or, on the other hand, the presence of harmful substances, depressing the growth of lower plants, cause the noted selectiveness.

N. A. Krasil'nikov (1949b) suggests that weak development of lichens on certain rocks, for example, tufas, is due to antibacterial poisonous compounds of certain chemical elements. Sometimes differences in the chemical composition of rocks are so small that they can be detected neither by chemical nor physical methods, i.e., biological reagents in such cases are, as a rule, more sensitive.

Our observations on the distribution of lichens on rocks, particularly granites, under conditions of the southern part of the Far East showed that the highest development of lichens is noted on those rock outcroppings or blocks at the foot of slopes where water can for some reason be detained — in microfissures, depressions, rough spots. Therefore, it is not accidental that of two adjacent "equally old" blocks of granite, but with different moisture conditions, one is covered with lichens and the other with only a "thin sun-burned crust." Therefore, water — or, in other words, the degree of moisture — emerges here as the starting point for the development of lithophytic flora, the intensive factor of biological weathering. This, evidently, is a specific characteristic of weathering conditions in the southern territory of the Far East which experiences heavy moisture because of the monsoon climate. Here the processes of weathering of rocks and minerals are in general /34
more intensive than in other territories of our country also in the moderate climate zone, which we noted earlier (Ivashov, Bardyuk, 1968) on the basis of a mineralogical study of the present weathered crust in mountainous regions.

It must be noted that extremely typical is the adaptation of lichens not only to certain rocks, but also to minerals. Senft (1871) established that in granite rocks lichens primarily prefer to settle on oligoclase, to a lesser degree on orthoclase and mica, and are completely absent in quartz.

G. G. Lemmleyn (1936) described a different degree of adaptation of lichens to minerals. In particular, according to his data, lichens settle on smaller crystalline particles of prochlorite covering large crystals of rock crystal (quartz), while smooth facets of quartz crystals, not covered with prochlorite, are practically uncolonized by lichens. The physical and chemical properties of prochlorite are, therefore, more favorable for colonization and life processes of lichens than quartz.

The extremely important role of the physical and chemical properties of minerals for the growth of lichens has been indicated by Brisson (1880), Weddel (1873) and Stahlecker (1906). As these researchers have established, lichens give preference to those minerals which are characterized by the greatest basicity, i.e. by a high content of calcium and magnesium. On such minerals the thickness of the layers increases sharply, especially of crustaceous lichens.

According to the data of F. I. Levin (1949) in zone plagioclases lichens are most often adapted to the inner, more basic (alkaline) part of the grain, and its acid part, the peripheral area, is less covered.

2. Mechanical disintegration of the mineral substratum by the root system of plants. The effect of this biological weathering factor is well known. First of all, in mountainous regions trees growing on rocks take root in cracks and crevices. According to the data of N. S. Podobedov (1964), in the cells of the roots of plants, particularly trees, great pressure develops, reaching 60-100 atmospheres. Therefore, tree roots are able to break even the most dense, massive-crystal rocks.

According to the calculations of B. D. Zaytsev (1965), roots of higher vascular plants are able to exert pressure on rocks reaching 10–15 kg/cm^2, as the result of which the soil forming matrix is subjected to slow mechanical crushing. The products of this crushing are subjected to further change under the effect of other weathering agents, including biological factors.

The wedge effect of root systems of higher plants in rock is indicated by I. I. Ilyushin (1964). /35

Mechanical disintegration of the substratum is especially characteristic of lithophytic flora, particularly lichens. These plant organisms in their life processes play an extremely important role in the weathering of rocks and minerals. E. Bachmann (1907), studying the effect of crustaceous epilithic lichens on granite, established that they unequally affect different minerals in granite. The strongest effect is experienced by mica. Its flakes are cleaved by hyphae of lichens. In addition, lichen hyphae penetrate rock along capillaries and microfissures, leading to gradual loosening of the bonds between minerals.

Besides this effect on the mineral substratum, according to the experimental studies of Fry (1924, 1927), lichens can tear away flakes of rock of the substratum and incorporate them in unchanged form into their own tissue.

Ye. A. Yarilova (1947) found that lichen hyphae penetrate 1-2 mm into rock, destroying various minerals encountered along the way: mica, feldspar, hornblende, epidote and more rarely, quartz. According to her studies, the destructive effect of lichens on the mineral substratum is enormous, although they penetrate to a very slight depth. The point is that by their action they destroy the continuity of the rock surface and lead to the formation of the first thin layer, the rudiment of a new natural hypergenic formation — soil.

F. I. Levin (1949) described the destruction of plagioclases in diorite by lichens. Lichen hyphae closely interweave the plagioclase grains, breaking them up into pieces. The mechanical effect of lichens on rock has been described by B. B. Polynov (1945, 1948), I. A. Assing (1949), Ye. A. Yarilova (1950), Ye. I. Parfenova and Ye. A. Yarilova (1962) and others.

3. The effect on the mineral substratum of enzymes released from the root hairs of plants. The character of this biological factor of weathering is that the surface of fine root hair endings of both higher autotrophic plants and saprophytes (fungi) is able actively to destroy the mineral substratum with enzymes — high-molecular catalysts of a protein nature which accelerate the course of biochemical reactions (Peyve, 1961). It has now been established that root systems can actively affect the mineral substratum only with the help of enzyme apparatus (Kuprevich, 1949); the most active is the enzyme activity of roots provided with mycorrhiza (the symbiotic association of the mycelium of a fungus with the roots of a higher plant).

According to Ya. V. Peyve (1961), the assimilation of carbon dioxide by plants is closely connected with oxidation-reduction reactions, i.e. with the activity of oxidation-reduction enzymes whose function is to catalyze oxidation-reduction reactions at the normal temperature for physiological processes. /36

According to the data of A. Ye. Vozbutskaya (1964), at the present time about 450 different enzymes are known, divided according to their structure into two groups. The first group includes enzymes having catalytic properties and composed exclusively of protein. The second group includes enzymes composed of both protein and nonprotein parts, i.e. co-enzymes, which are the most active and enter into chemical interaction with the mineral substratum.

Enzymes are contained in every cell of living organisms which inhabit the soil (Peyve, 1961), i.e. bacteria, fungi, algae, etc. The humus horizon contains the largest amount of different enzymes, as the main mass of microorganisms is found here. In horizons A_2 and B as well as in the soil-forming matrix, enzymes are found in much smaller amount.

Because of plant roots dying off and the autolysis of microorganism cells, especially putrefactive bacteria, enzymes accumulate in soils, acting as biological catalysts in oxidation-reduction reactions of organic material. Thanks to the effect of enzymes, the end products of biochemical reactions in soils include carbon dioxide, hydrogen sulfide, methane, hydrogen and ammonia.

4. The effect on the mineral substratum of carbon dioxide released by the roots of plants. This process has been especially well studied in carbonate rocks and experimentally proved by Liebig and Sachs (Glinka, 1931) and Kunze and Chapek (Omelyanskiy, 1953) on a polished marble slab. It was shown that the corrosion of marble is due to the effect of carbon dioxide released by plant roots which converts calcium carbonate $CaCO_3$ to a solute compound $CaH_2(CO_3)_2$.

Stoklaza and Aberson (Glinka, 1931) are of the opinion that the only factor which has an extremely strong effect on the mineral substratum is carbon dioxide released by the roots of plants. This compound has a harmful effect not only on lime rock, but also on silicate, causing kaolinization of aluminosilicates.

The intensity of the action of this biological weathering factor lies in the fact that together with carbon dioxide, living plants continuously supply to the soil H-ions, released from root hair endings (Keller, 1963), as the result of which an acid medium is created around root hairs which also destroys /37
adjacent minerals. Root hairs of plants exchange H-ions for calcium, magnesium, potassium and other chemical elements of the mineral substratum, subjecting it to the most damaging action.

According to the data of Lewis and Ensminger (1948), the roots of primitive plants generate exceptionally high concentrations of H-ions, sufficient to cause weathering of field states in fresh rocks.

As is the opinion of Ya. V. Peyve (1961), the most important biochemical factor — carbon dioxide — is formed in soil as the result of life processes not only of plant roots but also those of microorganisms. As carbon dioxide dissolves in water, carbonic acid is formed, which dissociates in soils with the formation of hydrogen ions.

Besides H-ions, continuously released by the roots of plants, the soil also contains H-ions formed by the dissociation of biochemically-developing carbonic acid. Although the nature of H-ions in the soil differs, the character of their effect is the same, i.e., they interact with aluminosilicates and force out cations. In addition, carbonic acid formed in soils can carry out complete hydrolysis of silicates independently of H-ions released by the root hairs of plants.

5. The effect on the mineral substratum of certain acid organic compounds released by the roots of plants. The decomposition of the mineral substratum under the effect of this biological weathering factor has been shown experimentally (Glinka, 1931; Gorshkov, Yakusheva, 1962; Zaytsev, 1965), but the character of the organic materials themselves is completely unknown.

According to the data of Weinstein, Robbins and Perkins (1954) and Schatz et al., (1954, 1955), several organic liquids, released by plant roots, can be strong complexing agents able to dissolve chemical elements of minerals.

Lithophytic flora — lichens — are of very great importance as a biological weathering factor; like root hairs of plants they release acid organic and inorganic compounds to the mineral substratum. According to Zahlbruckner (1907), lithophytic flora are more closely connected to the mineral substratum than highly-developed green plants, as in lichens, especially in the most wide-spread crustaceous forms, the release of material predominates over assimilation. This causes the dissolution and then entrance into lichen tissue of chemical elements contained in the matrix minerals.

Zopf (1903) established that the mineral composition of the substratum affects the formation of lichen acids, which have high chemical activity. /38

Interesting studies of the mechanism of destruction of the substratum by lichens were made by Bachmann (1890). He showed that lichens, taking root in the mineral substratum, dissolve the latter with acid products. This researcher connected the chemical effect of lichens on their substratum with a high concentration of carbon dioxide and oxygen in the lichen medium.

According to the data of Kunze (1906) and Lind (1898), organic acids are extremely strong biological weathering factors, particularly oxalic acid released by fungous hyphae of lichens. According to Correns (1940), lichens can simultaneously release both organic acids and enzymes, which act jointly on the mineral substratum.

V. O. Tauson (1948) shows that during their life processes, along with carbon dioxide, mold fungi also form organic acids, for example: acetic, oxalic, lactic and citric acids, sometimes in quite large quantitites. These acids are much stronger than carbonic acid. They easily and freely destroy the mineral substratum.

Ye. A. Yarilova (1947) and Ye. I. Parfenova and Ye. A. Yarilova (1962) are of the opinion that lichen acid compounds, being polyhydric-polycarbon acids, have an extremely great chemical effect on rocks and individual minerals.

Acid discharges from the root hairs of plants are closely related to organic acids in soils. As the result of the life processes of microorganisms and the discharges from plant roots, as well as the decay of plant residue, low-molecular organic acids are formed in soils — acetic, formic, isocitric, lactic, oxalic, tartaric, malic, succinic, gluconic, butyric, fumaric, etc. (Kononova, 1951; Peyve, 1961). These compounds have a great effect on the general acidity of the soil and on the dynamics of mobile cations and anions in the soil.

Hakomori (1931), A. V. Pavlinova (1949), Ye. I. Sokolova (1966), Yu. Yu. Bugel'skiy (1968), A. I. Yershova (1968) and L. A. Matveyeva (1968) showed experimentally the effect of low-molecular organic acids on the mineral substrate — oxalic, tartaric, citric, asparaginic, maleic, acetic, butyric, succinic, etc. It has been established that these acids do not have the same decomposing effect on the mineral substratum. The most energetic are citric and tartaric acids, the weakest are asparaginic and succinic acids. The decomposition of minerals under the effect of these acids is accompanied by the dissolution not only of aluminum and iron, but also other chemical components, /39 especially alkalis and alkaline earth metals. Even more aluminum oxide turns into citric acid than fulvic acid. In addition, it has been established that the complexing effect of organic acids promotes the dissolution of silicic acid.

6. The effect of humus material and its derivatives on the mineral substratum. According to Ya. V. Peyve (1961), humus materials are formed in the soil as the result of biochemical decay and subsequent synthesis of organic matter. The sum total of organic matter in soil is composed of two parts — humified and non-humified. The humified part consists of humic and other humus acids, formed as the result of life processes of different groups of microorganisms and condensation reactions. The non-humified part of organic matter consists of living and dead tissues of plants, animals and microorganisms and their products of decay.

The humified part of organic matter is most active as a factor of biological weathering, the essence of which is the effect of humus acids on the mineral substratum (humus acids include humic and fulvic acids).

The active role of humic acid appears in oxidation-reduction reactions connected with the presence of functional groups in its composition (Peyve, 1961; Vozbutskaya, 1964): carboxyl, alcohol, methoxyl, carbonyl and quinone groups and phenol hydroxyls. Each of these groups has its own characteristic biochemical activity. Carboxyl groups and in part phenol hydroxyls are responsible for the ability of humic acids to exchange H-ions for metal-cations:

potassium, sodium, calcium, magnesium, copper, zinc, etc. (Peyve, 1961). Quinone groups, which can serve as hydrogen acceptors, play an important role in oxidation reactions (Vozbutskaya, 1964).

Typical of fulvic acids (crenic and apocrenic acids) is a high degree of dissociation and a large number of acid groups (Ponomareva, 1947) which also is responsible for their greater activity than humic acids. Fulvic acids play an important role in podzolization of soil as they form dissolved complex compounds with ions of iron, aluminum and other metals. Because of the high mobility of the solutions, complex organo-mineral compounds pass to underlying horizons of the soil and precipitate there with certain oxidation-reduction potentials and the acid-base properties of the medium.

Experimental studies of the effect of humus acids on rocks and minerals made by Ye. P. Levando et al., (1966), Ye. I. Sokolova (1968), G. A. Levash- /40
kevich (1968) and A. I. Yershova (1968) indicate their extremely high activity. Under the effect of these natural compounds, various silicates disintegrate and basic chemical components, especially aluminum, are carried off. In the course of this process, along with products of decay of the mineral substratum and humus acids, complex organo-mineral compounds are formed, which under certain conditions promote the further migration of chemical elements or cause their precipitation from solutions in soils and in the present weathered crust.

The effect of organic matter in soil on the redistribution of chemical elements and its effect on the mineral substratum is described in the works of D. B. Khan (1951), S. S. Dragunov (1959), I. V. Aleksandrova (1960), M. M. Kononova (1951, 1963), M. M. Kononova and N. P. Bel'chikova (1960), M. M. Kononova, I. V. Aleksandrova and N. A. Titova (1964), T. V. Drozdova (1963), S. M. Manskaya and T. V. Drozdova (1964) and other researchers.

Soils formed on a mineral substratum under the influence of the disintegrating effect of lower and higher plants and organic compounds are never sterile, they always contain large amounts of microorganisms (Krasil'nikov, 1949; Mishustin, 1956) which perform a great deal of disintegrating work in relation to the mineral substratum. Properly, the initial change in rock in the earliest stages of soil formation is also due to microorganisms. Therefore, among factors of biological weathering connected with the life processes of plants and organisms, the basic role is played by various microorganisms, universally distributed in surface horizons of our planet — in the lithosphere, biosphere, hydrosphere and atmosphere (Tauson, 1948).

In the group of biological weathering factors developing in the life processes of microorganisms and animals, the following can be distinguished.

1. The effect on the mineral substratum of the simplest nonspecific microorganisms. The significance of this factor of biological weathering was quite clearly indicated by N. A. Krasil'nikov (1956): "In geology and soil science there has been the firm conviction that weathering and disintegration of rocks as the first step in the formation of soils occurs abiotically, under the effect of physical and chemical factors alone. However, this is not quite so: the zone of naked rock is not dead. It supports unique and quite interesting life — the life of lower organisms" (p. 177).

This factor of biological weathering appears everywhere under any climate conditions, even in rocks completely devoid of other kinds of life, at altitudes above 5000 m (Glazovskaya, 1952) and in the loose sands of the hot desert /41 (Tauson, 1948), lacking visible vegetation.

According to the data of N. A. Krasil'nikov (1956), on the surface layer of solid crystalline rocks, devoid not only of higher vegetation, but also of lichens, there is a weathered "crust" 1-2 mm thick, differing from the basic rock in color and colonized by different kinds of microbes. One gram of material from the weathered crust of rocks contains up to one million bacteria cells. The main mass of microorganisms consists of symbiotically free living nonsporiferous bacteria and microbacteria; there are small amounts of sporiferous bacteria and fungi, as well as Actinomycetes, algae and Azotobacter.

The mineral substratum serves as a source of nutrition for rock microbes. Under the effect of the life processes of these microorganisms, the mineral substratum is subjected to disintegration. According to the data of M. A. Glazovskaya (1950), in the surface weathered crust where the microorganisms live, mineral and chemical compositions are subject to change. In the clear weathered crust of granite significantly large amounts of calcium, magnesium, potassium and oxides of aluminum are found; there is often an accumulation of iron. It is very typical that in the weathered crust losses are approximately doubled during calcination and an increase is noted in the content of nitrous compounds and silicon. Here also occurs the formation of secondary minerals: hydrous mica, sericite, microcline, etc.

According to the data of V. O. Tauson (1948), bacterial flora of the weathered crust of alpine rocks is more primitive and differs markedly from the microflora of soil. He established that of bacteria, the main supplier of nitrogen on mountain tops are oligonitrophils and blue-green algae — which fix molecular nitrogen.

N. A. Krasil'nikov (1949a) established that bacteria and other microorganisms develop in the surface layer of rock in symbiosis with lichens. They use the organic discharges of lichens as energy material. In cases when lichens are absent on rock, microorganisms use the discharge of free living algae which almost always exist together with bacteria as a source of nutrition. In addition, bacteria and, probably, fungi and Actinomycetes are able themselves to assimilate carbon dioxide from the atmosphere and synthesize organic matter using energy formed with the oxidation of inorganic reduced compounds of rock. These bacteria — prototrophs — can exist without symbiosis with algae or lichens. These are the simplest protozoa — microbes settling on uninhabited lifeless rocks which prepare conditions for the existence of other microorganisms (Polynov, 1948). With their own acid discharges they destroy /42
rock and use the products of its decay — individual chemical elements and mineral compounds — as a source of nutrition during their further existence. In addition, prototrophs are able to synthesize in themselves nitric, nitrous and sulfuric acids and discharge them into the mineral substratum during the life

cycle (Isachenko, 1951; Omelyanskiy, 1953).

2. The activity of ferrobacteria. Ferrobacteria take part in the formation of mineral compounds in the zone of hypergenesis, being a kind of biological catalyst (Strakhov, 1947).

According to the data of N. G. Kholodnyy (1953), these microorganisms play an important role in the oxidation of ferrous oxide compounds in the zone of hypergenesis, existing both in solid minerals and in aqueous solutions (underground and surface waters). The result of activity of ferrobacteria is the conversion of ferrous oxide into insoluble hydroxide of this metal.

S. I. Kuznetsov, M. V. Ivanov and N.N. Lyalikova (1962) indicate the dual role of ferrobacteria in the zone of hypergenesis. First of all, these researchers point out the oxidizing role of threadlike ferrobacteria; secondly, they feel that some forms of ferrobacteria take part in the creation of the reduction situation in the zone of hypergenesis, i.e., they promote conversion of immobile ferric oxide into mobile ferrous oxide.

The reduction rôle of ferrobacteria in the zone of hypergenesis is indicated by many researchers (Gabe, Troshanov, Sherman, 1964; Troshanov, 1964; Halvorson and Starkey, 1927; Roberts, 1947; Betremieux, 1951; Iwaschow, 1968).

Closely affiliated with ferrobacteria are manganic bacteria, which in the zone of hypergenesis exist together with ferrobacteria and take part in the redistribution of manganese and iron compounds in deposits. Manganic bacteria also encompass kinds which fix and accumulate trivalent manganese. However, there are also bacteria which are able to reduce manganic oxide compounds to manganous in the present weathered crust (Ivashov, 1968).

Life processes of manganese bacteria in soils, in water, in present sediments of water basins, as well as in manganese ores of sedimentary origin are dealt with extensively in the literature (Ten-Khak-Mun, 1967; Sokolova-Dubinina, Deryugina, 1966, 1967, 1968; Shterenberg, 1967; Gabe, Troshanov, Sherman, 1964; Kossaya, 1967, and others).

3. The activity of sulfate reducing bacteria. Sulfate reducing bacteria reduce sulfates, producing hydrogen sulfide and, therefore, take part in the distribution of mineral compounds of chemical elements of varying valency in the zone of hypergenesis. The scale of this process is quite extensive, as it has been established that sulfate reducing bacteria are spread practically /43 everywhere in the biosphere and hydrosphere (Baas-Bekking et al., 1963), and as a result the greater part of hydrogen sulfide on the earth's surface is of biogenic origin (Tauson, 1948).

It has now been established (Galstyan, 1966) that reduction of sulfates, for example in soils, occurs with the participation of sulfate reductase — an enzyme catalyzing this process and resulting from the activity of microorganisms in both acid and alkaline conditions of the medium.

The ecological characteristics of sulfate-reducing bacteria and the mechanisms of the reduction of sulfates with their assistance have been dealt with by numerous researchers (Nadson, 1903; Gorovits-Vlasova et al., 1932; Rubenchik, 1947; Birshtekher, 1957; Liss, 1957; Degens, 1967).

4. The activity of thionic bacteria (sulfur bacteria). Thionic bacteria play an exceptionally important role in the oxidation of sulfide polymetallic deposits and in the redistribution of sulfur in the zone of hypergenesis (Kuznetsov, Ivanov, Lyalikova, 1962). The scale of this process can be estimated by the fact that the majority of sedimentary deposits of syngenetic and epigenetic sulfur is of biogenic origin and biogenic oxidation (weathering) of sulfide polymetallic deposits occurs in all climate zones of the earth's surface and is 10 times more intense than chemical weathering, which has been proved experimentally (Kuznetsov, 1959).

Until recently it was assumed that the oxidation of sulfide deposits takes place only chemically (Smirnov, 1955). However, thionic bacteria, first ascertained by Colmer and Hinkle (1947), as was later shown, play a large role in the oxidation of sulfide ores. Now it has been established that practically all oxidized ores of sulfide deposits, both in dumps and in ore bodies of deposits, contain thionic bacteria. In ore bodies of deposits, bacterial oxidizing processes are localized along cracks, i.e. where atmospheric precipitation and ground water penetrate. Oxidation is most intense in partially disintegrated ores and ore-mixed rocks in which, according to the data of G. I. Karavayko (1960), the number of bacteria cells reaches 100,000 per 1 g of ore.

Many authors have devoted their studies to thionic bacteria (Zarubina, Lyalikova, Shmuk, 1959; Lyalikova, 1961; Lyalikova, Deryugina, 1966; Boychenko, 1967; Gorlenko, 1968; Templ and Colmer, 1951; Bryner, Beck, Davis and Wilson, 1954; Ashmeed, 1955).

5. The activity of silicate bacteria. Silicate bacteria, according to the studies of V. G. Aleksandrov (1953), are an extremely interesting biological factor of the weathering of aluminosilicates. They are related to crypto- /44 gamous bacteria which have a significant effect on the soil formation process. These microorganisms destroy aluminosilicates of the mineral substratum and soils formed on them.

As shown by V. G. Aleksandrov (1953), silicate bacteria could be the first organisms to destroy silicates and aluminosilicates of rocks at the dawn of life on our planet. With the appearance of other anaerobic bacteria, the role of silicate bacteria became more complex, as the effect of these microorganisms could be suppressed or stimulated by other developing microorganisms, although silicate bacteria at the present time are also widely developed in the zone of hypergenesis and they take part in the biogenic destruction of aluminosilicates.

The effect of silicate bacteria on aluminosilicates, for example on mica (muscovite), lies in the fact that, decomposing this mineral, they free from it potassium which becomes mobile and accessible to plants. Silicate bacteria draw phosphorous out of phosphorites and apatites and nitrogen from the air. In soil the most favorable conditions for life processes of silicate bacteria occur around the roots of plants, i.e. these microorganisms are to some degree rhizospheric. Symbiosis exists between silicate bacteria, freeing mobile chemical elements from aluminosilicates, and plants which absorb the freed mobile chemical elements. This symbiosis favorably affects the growth and development of plants (Aleksandrov, 1953).

The great importance of silicate bacteria as a biological factor of weathering is that these microorganisms are distributed in all topographical-climate zones on the surface of the earth (Aleksandrov, 1953).

The destruction of aluminosilicates and silicates by microorganisms, including silicate bacteria, is described by V. I. Vernadskiy (1934), A. P. Vinogradov and Ye. A. Boychenko (1942), L. Ye. Novorossova, N. P. Remezov and N. N. Sushkina (1947), V. G. Aleksandrov and G. A. Zak (1950), M. A. Messinevoy (1961), I. N. Antipov-Karatayev and I. G. Tsyuripa (1966), S. S. Chekin (1967), K. Bassalik (1912), L. R. Moore (1964) and others.

6. The activity of heterotrophic bacteria. Heterotrophic bacteria play an enormous role in the destruction of organic matter in the zone of hypergenesis to the simplest compounds (Peyve, 1961; Kononova, 1963). With the joint effect of these microorganisms and organic matter, which serves as a source of energy for heterotrophs, a reduction medium can develop locally in the zone of hypergenesis. As is known, reduction conditions very strongly affect the redistribution of chemical elements of varying valency — iron, manganese, copper, nickel, vanadium, etc.

Heterotrophic microorganisms include the group of methane-forming bacteria (Baas-Bekking et al., 1963) which takes a very active part in the destruction of organic matter. They are most usually found in anaerobic media, where plant material is accumulated and causes the formation of large amounts of carbon dioxide and methane. /45

7. The effect of living organisms on the mineral substratum. This factor of biological weathering has received very little study. Usually it is reduced to the fact that animals directly or indirectly affect the destruction of rocks on the surface of the earth. In some cases certain animals tamp down loose rock and in other cases, just the opposite, they loosen deposits by making burrows, passageways, etc., in them, at the same time affecting the mineral substratum with their life products. The most significant role in this respect is played by earthworms, ants, termites, etc., which make narrow but numerous and long underground passages, allowing air with moisture and carbon dioxide to penetrate into the depths of loose rock (soil), promoting chemical weathering (Podobedov, 1964).

Extremely interesting in this respect are the studies made by Perel, Karpacevskij and Jegorova (1966) of the activity of earthworms. These studies established that the decomposition of fallen leaves with the participation of earthworms leads to the accumulation in the soil of humic acid compounds containing a significant number of acid groups. These also explain the high content of exchange hydrogen in soil formed on poor silicate sand, resulting in the formation of humified horizon A_1 whose organic matter resembles the humus of weakly-podzolized soil. In the absence of earthworms (control tests) the disintegration of fallen leaves proceeded without marked humification of the soil.

These data indicate that biological factors of the weathering of rocks and minerals play an extremely important role. There is a close connection and continuity between these factors in weathering processes. For example, this can be traced through a group of biological weathering factors arising during the development of vegetation. First of all the first microorganisms — prototrophs — settle on lifeless rocks, preparing conditions for the existence of other microorganisms — fungi, Actinomycetes, blue-green algae, etc. Life processes of these microorganisms create a favorable situation for the development and existence of lithophytic flora — lichens, whose place is taken by green mosses and then higher vascular plants. Simultaneously with this evolution of vegetation there occurs a kind of evolution in the formation of the weathered crust (soil), first from a barely noticeable extremely thin "sunburnt film" on lifeless uninhabited rocks to a weathered crust and normal soil cross section. /46

As the weathered crust (soils) is formed, the effect of organic compounds in plants and soils upon destruction processes of the mineral substratum is increased and life processes of microorganisms are amplified.

These several biological factors of the weathering of rocks and minerals in the zone of hypergenesis exist in mutual interrelationship, characterized by strict direction, increasing without interruption. In terms of the character and rate of the destructive effect on rocks and minerals, they significantly exceed chemical processes.

Evidently, some processes in the weathering of rocks and minerals which are chemical are influenced by certain biological weathering factors, which play a catalytic role.

Study of the role of biological factors of weathering is very important in determining the evolution of minerals and individual chemical elements in the zone of hypergenesis.

REFERENCES

1. Aleksandrov, V. G. Silikatnye bakterii (Silicate bacteria). Moscow, Sel'khozgiz, 1953.

2. Aleksandrov, V. G. and G. A. Zak. Bacteria which destroy aluminosilicates (silicate bacteria). Mikrobiologiya, No. 19, Issue 2, 1950.

3. Aleksandrova I.V. A method of studying the qualitative composition of organic matter in soil solutions. Pochvovedeniye, No. 11, 1960.

4. Antipov-Karatayev, I.N. and I.G. Tsyuripa. Rules of biochemical disintegration of albite and muscovite. In the collection: "Migratsiya khimicheskikh elementov pri protsessakh vyvetrivaniya (po eksperimental'nym dannym)" [The migration of chemical elements during weathering processes (according to experimental data)]. Kora vyvetrivaniya (The weathered crust). No. 7, 1966.

5. Assing, I.A. Initial stages of weathering and soil formation in massive-crystal rock. Problemy sov. pochvovedeniya, 1949, Coll. No. 15.

6. Baas-Bekking, L.G., I. R. Kaplan and D. Mur. Range limits of pH and and oxidation-reduction potentials of natural media. In the collection: "Geokhimiya metageneza" (Geochemistry of metagenesis). Moscow, IL, 1963.

7. Birshtekher, E. Neftyanaya mikrobiologiya (Petroleum microbiology). Leningrad, Gostoptekhizdat, 1957.

8. Boychenko, Ye.A. On the evolution of oxidizing functions of the biosphere. Geokhimiya, No. 8, 1967.

9. Bugel'skiy, Yu.Yu. On the possibility of the migration of nickel in complex compounds with low-molecular organic acids. In the collection: "Geologiya i geokhimiya kor vyvetrivaniya" (The geology and geochemistry of weathered crusts) Kora vyvetrivaniya, No. 10, 1968.

10. Vernadskiy, V.I. Ocherki geokhimii (Writings on geochemistry). Moscow, ONTI, 1934.

11. Vernadskiy, V.I. Biogeokhimicheskiye ocherki 1922-1923 gg. (Biogeochemical writings 1922-1923). Moscow, Izd-vo AN SSSR, 1940.

12. Viktorov, V.S. Ispol'zovaniye geobotanicheskogo metoda pri geologicheskikh i gidrogeologicheskikh issledovaniyakh (The use of the geobotanical method in geological and hydrogeological research). Moscow, Izd-vo AN SSSR, 1955.

13. Vinogradov, A.P. and Ye. A. Boychenko. The disintegration of kaolin by diaton algae. Dokl. AN SSSR, Issue 37, No. 4, 1942.

14. Vozbutskaya, A. Ye. Khimiya pochvy (The chemistry of soil). Moscow, Izd-vo "Vysshaya shkola," 1964.

15. Vologdin, A.G. Geologicheskaya deyatel'nost' mikroorganizmov (The geological activity of microorganisms). Izv. AN SSSR, seriya geol., No. 5, 1947.

16. Gabe, D.R., E.P. Troshanov and E.E. Sherman. The formation of manganese-iron layers in silt as a biogenic process. In the collection: "Rol' mikroorganizmov v obrazovanii zhelezo-margantsevykh ozernykh rud" (The role of microorganisms in the formation of iron-manganese lacustrine ores). Moscow-Leningrad, Izd-vo "Nauka," 1964. /47

17. Galstyan, A.Sh. Opredeleniye aktivnosti sul'fatreduktazy pochvy. (The determination of the activity of soil sulfate reductase). Dokl. AN SSSR, Vol. 166, No. 4, 1966.

18. Ginzburg, I.N. The role of microorganisms in the weathering of rock and the formation of minerals. Kora vyvetrivaniya, No. 1, 1952.

19. Ginzburg, I.I., R.S. Yashina, L.A. Mateyeva, V.V. Belyatskiy and T.S. Nuzhdenovskaya. The disintegration of several minerals by organic acids. In the collection: "Khimiya zemnoy kory" (Chemistry of the earth's crust). Vol. 1, Moscow, Izd-vo AN SSSR, 1963.

20. Glazovskaya, M.A. The weathering of rock in the peneplain belt of Central Tien Shan. Trudy Pochvennogo in-ta AN SSSR, No. 34, 1950.

21. Glazovskaya, M.A. Biological factors of weathering in high-mountain regions. Priroda, No. 12, 1952.

22. Glinka, K.D. Pochvovedeniye (Soil science). Moscow-Leningrad, Sel'khozgiz, 1931.

23. Gorlenko, V.M. The effect of oxidation-reduction conditions of the medium and oxygen on the development of colored sulfobacteria in nature. Mikrobiologiya, Vol. XXXVII, No. 1, 1968.

24. Gorovits-Vlasova, L.M. et al. Experimental studies in fish canning. Trudy Tsentral'nogo NII biokhimii i pishchevoy promyshlennosti, Issue 4, 1932.

25. Gorshkov, A.P. and A.F. Yakushova. Obshchaya geologiya (General geology). Moscow, Izd-vo MGU, 1962.

26. Degens, E.T. Geokhimiya osadochnykh obrazovaniy (Geochemistry of sedimentary formations). Moscow, Izd-vo "Mir," 1967.

27. Dragunov, S.S. The formation of humic acids under various natural conditions. In the collection: "Genezis tverdykh goryuchikh iskopayemykh" (The origin of solid fossil fuels). Moscow, Izd-vo AN SSSR, 1959.

28. Drozdova, T.V. The role of humic acids in the geochemistry of soil Pochvovedeniye, No. 5, 1963.

29. Yershova, A.I. Some data on the study of the disintegrating effect of humic acids on minerals. In the collection: "Geologiya i geokhimiya kor vyvetrivaniya" (Geology and geochemistry of weathered crusts). Kora vyvetrivaniya, Issue 10, 1968.

30. Zaytsev, B.D. Pochvovedeniye (Soil science). Moscow, Izd-vo "Lesnaya promyshlennost'", 1965.

31. Zarubina, Z.M., N.N. Lyalikova and Ye.I. Shmuk. A study of microbiological oxidation of pyrite in coal. Izv. AN SSSR, OTH, No. 1, 1959.

32. Ivashov, P.V. On biological factors of the weathering of rocks and minerals. In the collection: "Voprosy geograficheskogo izucheniya Dal'nego Vostoka." (Questions of the geographical study of the Far East). Khabarovsk, Khabarovskoye knizhnoye izd-vo, 1965.

33. Ivashov, P.V. The effect of biogeochemical processes on the thermodynamic equilibrium of manganese compounds in soils of southern Far East. In the collection; "Geomorfologicheskiye, landshaftnye i biogeokhimicheskiye issledovaniya v Priamur'ye." (Geomorphological, landscape and biogeochemical studies in the Amur Region). Moscow, Izd-vo "Nauka," 1968.

34. Ivashov, P.V. and V.V. Bardyuk. Mineralology and geochemistry of brown forest soils on the tin ore bed of the Far East. In the collection: "Geomorfologicheskiye, landshaftnye i biogeokhimicheskiye issledovaniya v Priamur'ye." (Geomorphological, landscape and biogeochemical studies in the Amur Region). Moscow, Izd-vo "Nauka," 1968.

35. Isachenko, B.L. Microorganisms as a geological factor. Izbrannye trudy, Vol. II. Moscow, Izd-vo AN SSSR, 1951.

36. Karavayko, G.I. The role of thionic bacteria in the oxidation of sulfide ores of the Kafan bed. Mikrobiologiya, No. 35, Issue 6, 1966.

37. Keller, U.D. Fundamentals of chemical weathering. In the collection: "Geokhimiya litogeneza" (Geochemistry of lithification). Moscow, IL, 1963.

38. Krasil'nikov, N.A. The role of microorganisms in the weathering of rocks. 1. Microflora of the surface layer of rock. Mikrobiologiya, No. 17, Issue 4, 1949a.

39. Krasil'nikov, N.A. The role of microorganisms in the weathering of rocks. 2. Focal distribution of microorganisms on the surface of rocks. Mikrobiologiya, No. 18, Issue 4, 1949b.

40. Krasil'nikov, N.A. Microflora of alpine rock and its nitrogen fixing activity. Uspekhi sovr. biol., No. 41, Issue 2, 1956.

41. Krasnov, A.N. A study of the history of the development of flora in the southern part of Eastern Tien Shan. Zap. Russk. geograf. ob-va, No. 19, 1888. /48

42. Kononova, M.M. Problema pochvennogo gumusa i sovremennye zadachi yego izucheniya (The problem of soil humus and present aims of its study). Moscow, Izd-vo AN SSSR,1951.

43. Kononova, M.M. Organicheskoye veshchestvo pochvy, yevo priroda, svoystva i metody izucheniya (Organic matter of soil, its nature,

properties and methods of study). Moscow, Izd-vo AN SSSR, 1963.

44. Kononova, M.M., I.V. Aleksandrova and N.A. Titova. The disintegration of silicates by organic matter of the soil. Pochvovedeniye, No. 10, 1964.

45. Kononova, M.M. and N.P. Bel'chikova. On the study of the nature of humus material of the soil by fractionation methods. Pochvovedeniye, No. 11, 1960.

46. Kossaya, T.A. On the composition of manganese oxides in cultures of Metallogenium and Leptothrix. Mikrobiologiya, No. 36, Issue 6, 1967.

47. Kuznetsov, S.I. The geological activity of microorganisms. Vestnik AN SSSR, No. 2, 1959.

48. Kuznetsov, S.I. Biogeokhimiya sery (The biogeochemistry of sulfur). Izv. SSSR, seriya biol., No. 5, 1963.

49. Kuznetsov, S.I., M.V. Ivanov and N.N. Lyalikova. Vvedeniye v geologicheskuyu mikrobiologiyu (Introduction to geological microbiology) Moscow, Izd-vo AN SSSR, 1962.

50. Kuprevich, V.F. Extracellular enzymes of the roots of higher autotrophic plants. Dokl. AN SSSR, Vol. 68, No. 5, 1949.

51. Levando, Ye.P., V.M. Krasikova, Ye.V. Kiselev, I.A. Tereshenkova and G.M. Stepanova. Investigation of the solubility of metapicrites and chlorite-amphibole schist in natural organic acids in connection with a study of bauxite-formation conditions. In the collection: "Migratsiya khimicheskikh elementov pri protsessakh vyvetrivaniya (po eksperimentalnyk dannym)" [The migration of chemical elements in weathering processes (according to experimental data)]. Kora vyvetrivaniya, Issue 7, 1966.

52. Levashkevich, G.A. The interaction between humus acids and ion forms of iron and aluminum. In the collection: "Geologiya i geokhimiya kor vyvetrivaniya" (Geology and geochemistry of weathered crusts). Kora vyvetrivaniya, Issue 10, 1968.

53. Levin, F.I. Rol' lishaynikov v vyvetrivanii izvestnyakov i dioritov (The role of lichens in the weathering of limestones and diorites). Vestnik MGU, No. 9, 1949.

54. Lemmleyn G.G. Lichens and mosses on crystals of quartz and chlorite. Priroda, No. 4, 1936.

55. Liss, G. Biokhimiya avtotrophnykh bakteriy (The biochemistry of autotrophic bacteria). Moscow, IL, 1958.

56. Lyalikova, N.N. The role of bacteria in the oxidation of sulfide ores of the copper-nickel beds of the Kol'skiy peninsula. Mikrobiologiya, No. 30, Issue 1, 1961.

57. Lyalikova, N.N. and Z.P. Deryugina. Microbiological examination of several sulfide deposits of Northern Caucasia. Mikrobiologiya, No. 35, Issue 6, 1966.

58. Manskaya, S.M. and T.V. Drozdova. Geokhimiya organicheskogo veshchestva (Geochemistry of organic matter). Moscow, Izd-vo "Nauka," 1964.

59. Matveyeva, L.A. Some questions of the disintegration of minerals by simple organic acids. In the collection: "Geologiya i geokhimiya kor vyvetrivaniya" (Geology and geochemistry of weathered crusts) Kora vyvetrivaniya, Issue 10, 1968.

60. Messineva, M.A. The geological activity of bacteria and its effect on geochemical processes. In the collection: "Geologicheskaya deyatel'nost mikroorganizmov" (The geological activity of microorganisms). Trudy In-ta microbiol. AN SSSR, Issue 9, 1961.

61. Mishustin, Ye.N. Mikroorganizmy i plodorodiye pochvy (Microorganisms and the fertility of soil). Moscow, Izd-vo AN SSSR, 1956.

62. Nadson, G.A. Microorganisms as geological agents. Trudy Komissii issledovaniya mineral'nykh vod g. Slavyanska, St. Petersburg, 1903.

63. Novorossova, L.Ye., N.P. Remezov and N.N. Sushkina. The destruction of aluminosilicates by soil bacteria. Dokl. AN SSSR, Vol. 58, No. 4, 1947.

64. Omelyanskiy, V.L. The role of microorganisms in the weathering of rock. Izbrannye trudy, Vol. 1, Moscow, Izd-vo AN SSSR, 1953.

65. Pavlinova, A.V. Tartrate compounds of trivalent iron. Zh. org. khim., Issue 2, 1949.

66. Parfenova, Ye.I. and Ye.I. Yarilova. Mineralogicheskiye issledovaniya v pochvovedenii (Mineralogical studies in soil science). Moscow, Izd-vo AN SSSR, 1962.

67. Peyve, Ya.V. Biokhimiya pochv. (Biochemistry of soils). Moscow, Sel'khozgiz, 1961.

68. Plyusnin, I.I. Meliorativnoye pochvovedeniye (Meliorative soil science) /49
Moscow, Izd-vo "Kolos," 1964.

69. Podovedov, N.S. Obshchaya fizicheskaya geografiya i geomorfologiya (General physical geography and geomorphology). Moscow, Izd-vo "Nedra," 1964.

70. Polynov, B.B. First stages of soil formation in massive-crystal rocks. Pochvovedeniye, No. 7, 1945.

71. Polynov, B.B. On the question of the role of elements of the biosphere in the evolution of organisms. Pochvovedeniye, No. 10, 1948.

72. Ponomareva, V.V. On methods extraction and the chemical nature of fulvic acids. Pochvovedeniye, No. 12, 1947.

73. Ravich-Shcherbo, Yu.A. On the role of microorganisms in the weathering of rocks. Arkhiv biologicheskikh nauk, No. 28, Issue 3, 1928.

74. Rubenchik, L.I. Sul'fatredutsiruyushchiye bakterii. (Sulfate reducing bacteria). Moscow-Leningrad, Izd-vo AN SSSR,1947.

75. Smirnov, S.S. Zona okisleniya sul'fidnykh mestorozhdeniy (The zone of oxidation of sulfide deposits). Moscow, Izd-vo AN SSSR,1955.

76. Sokolova, Ye.I. On complex compounds of iron and aluminum with low-molecular organic acids. In the collection: "Migratsiya khimicheskikh elementov pri protsessakh vyvetrivaniya (po eksperimental'nym dannym)" (The migration of chemical elements in weathering processes (according to experimental data)). Kora vyvetrivaniya, Issue 7, 1966.

77. Sokolova, Ye.I. On the disintegration of nepheline and biotite by humus acids. In the collection: "Geologiya i geokhimiya kor vyvetrivaniya" (The geology and geochemistry of weathered crusts). Kora vyvetrivaniya, Issue 10, 1968.

78. Sokolova-Dubinina, G.A. and Z.P. Deryugina. The participation of microorganisms in the formation of oxidized ores of the Chiatura manganese deposit. Mikrobiologiya, No. 35, Issue 2, 1966.

79. Sokolova-Dubinina, G.A. and Z.P. Deryugina. The role of microorganisms in the formation of rhodochrosite in Lake Punnus-Yarvi. Mikrobiologiya, No. 36, Issue 3, 1967.

80. Sokolova-Dubinina, G.A. and Z.P. Deryugina. The effect of the conditions of a lake medium on the microbiological formation of manganese ore. Mikrobiologiya, No. 37, Issue 1, 1968.

81. Strakhov, N.M. Speech in connection with the report of A.G. Vologdin. "Geologicheskaya deyatel'nost' mikroorganizmov." (Geological activity of microorganisms). Izv. AN SSSR, seriya geol., No. 5, 1947.

82. Tauson, V.O. Velikiye dela malen'kikh sushchestv. (Great works by small creatures). Moscow-Leningrad, Izd-vo AN SSSR, 1948.

83. Ten-Khak-Mun. Mikroorganisms, oxidizing iron and manganese in the soils of the southern part of Sakhalin. Mikrobiologiya, 1967, No. 36, Issue 2, 1967.

84. Troshanov, E.P. Bacteria reducing manganese and iron in ground deposits. In the collection : "Rol' mikororganizmov v obrazovanii zhelezo-margantsevykh ozernykh rud" (The role of microorganisms in the formation of iron-manganese lake ores.) Moscow-Leningrad, Izd-vo "Nauka," 1964.

85. Tyulina, L.K. On the evolution of vegetation of the foothills of the Southern Urals. Trudy Zlatoustovskogo ob-va krayevedov i Gosudarstv. Il'menskogo zapovednika, Issue 1. Zaltoust, 1928.

86. Khan, D.B. On a method of studying the composition of water-soluble organic matter of plant residue. Trudy Pochvennogo in-ta im. V. V. Dokuchayeva, No. 38, 1951.

87. Kholodnyy, N.G. Zhelezobakterii (Ferrobacteria). Moscow, Izd-vo AN SSSR, 1953.

88. Chekin, S.S. On finding fossil microorganisms in some crystals of kaolinite. Litol. i polez. iskop., No. 2, 1967.

89. Chernyakhovskiy, A.G. Elyuviy i produkty yego pereotlozheniya (Kazakhstan i Srednyaya Aziya) (Eluvium and products of its redeposition (Kazakhstan and Middle Asia)). Moscow, Izd-vo "Nauka," 1956.

90. Chernyakhovskiy, A.G. Some questions of physical and physico-chemical weathering of rock. In the collection: "Geologiya i geokhimiya kor vyvetrivaniya" (Geology and geochemistry of weathered crusts). Kora vyvetrivaniya, Issue 10, 1968.

91. Shterenberg, L.Ye. On biogenic structures in manganese ores. Mikrobiologiya, No. 36, Issue 4, 1967.

92. Yarilova, Ye.A. The role of lithophytic lichens in the weathering of massive-crystal rocks. Pochvovedeniye, No. 9, 1947.

93. Yarilova, Ye.A. The transformation of syenite minerals in the first stages of soil formation. Trudy Pochvennogo in-ta im. V. V. Dokuchayeva, No. 34, 1950.

94. Yaroslavtsev, I.N. Biological factors of weathering in high mountain /50
regions. Priroda, No. 12, 1952.

95. Ashmeed, D. The influence of bacteria on the formation of acid mine waters. Colliery Guard, No. 190, 1955.

96. Bachmann, E. Connections between lichens and their substratum. Ber. Dtsch. bot. Ges., No. 8, 1890.

97. Bachmann, E. Granite occupation of lichens. Pringsh. Jahrb. wiss. Bot., Vol. 44, No. 1, 1907.

98. Bassalik, K. Silicate decomposition by soil bacteria. Z. Gärungsphysiologie, No. 2, 1912.

99. Betremieux, R. An experimental study of the evolution of iron and manganese in the soil. Ann. agron., No. 2, 1951.

100. Brisson. Lichens in the vicinity of Chateau Thierry. Mem. Soc. agric. sci. et arts. Marne, 1880.

101. Bryner, L. J. Beck, D. Davis and D. Wilson. Microorganisms in leaching sulfide minerals. Industr. and Engng. Chem., Vol. 46, No. 12, 1954.

102. Colmer, A.R. and N. Hinkle. The role of microorganisms in acid mine drainage. Science, No. 106, 1947.

103. Correns, C. The chemistry of the weathering of silicate. Naturwissenschaften, Jahrg. Vol. 28, No. 24, 1940.

104. Fry, J. A suggested explanation of the mechanical action of lichens (lithophytic lichens on rocks). Ann. Bot., No. 38, 1924.

105. Fry, J. The mechanical action of crustaceous lichens on substrata of shale, schist, gneiss, limestone and obsidian. Ann. Bot., No. 41, 1927.

106. Hakomori, Sh. On the relations of several metallic ions in the presence of organic acids. Sci. Repts. Tohoku Univ., No. 4, 1931.

107. Halvorson, H.O. and R.L. Starkey. Studies on the transformation of iron in nature. Pt. 2. Concerning the importance of microorganisms in the solution and reduction of iron. No. 24, 1927.

108. Iwaschow, P.W. Biogeochemical processes in the formation of siderites. Geologie, No. 3, 1968.

109. Kunze, F. On acid discharges of roots and hyphae of fungi and their importance. Pringsh. Jahrb. wiss. Bot., No. 42. 1906.

110. Lewis, C.C. and W. S. Eisenmenger. Relationship of plant development of capacity to utilize potassium in orthoclase feldspar. Soil Sci., Vol. 65, No. 6, 1948.

111. Lind, K. On the penetration of fungi in limestone and bone. Pringsh. Jahrb. wiss. Bot., No. 32, 1898.

112. Moore, L.R. The in situ formation and development of some kaolinite macrocrystals. Clay Minerals Bull. Vol. 5, No. 31, 1964.

113. Perel, T.S., L.O. Karpacevskij and S.V. Jegorova. An experimental study of the effect of earthworms on the substratum and humus horizon of forest soil. Pedobiologia, Vol. 6, No. 3-4, 1966.

114. Roberts, J.L. Reduction of ferric hydroxide by strains of Bacillus polymyxa. Soil Sci., No. 63, 1947.

115. Schatz et al. Chelation (sequestration) as a biological weathering factor in pedogenesis. Proc. Tenn. Acad. Sci., No. 28, 1954.

116. Schatz et al., Significance of lichens as pedogenic (soil forming) agents. Proc. Tenn. Acad. Sci., No. 30, 1956.

117. Senft, F.Z. Dtsch. geol. Ges., No. 23, 1871.

118. Stahlecker, E. A study of thallus culture and thallus formation in connection with the substratum in the silicification of crustaceous lichens. Funfstuks. Beitr. wiss. Bot., No. 5, 1906.

119. Temple, K. and A. Colmer. The autotrophic oxidation of iron by a new bacterium Thiobacillus ferrooxidans. J. Bacteriol., No. 62, 1951.

120. Weddel, H. On the role of the substratum in the distribution of saxicolous lichens. C.R.T., No. 76, 1873.

121. Weinstein, L.H., W.R. Robbins and H.F. Perkins. Chelating agents and plant nutrition. Science, No. 1306, 1954.

122. Zahlbruckner, A. Lichens a specific part in natural plant families, listed by A. Engler and K. Pronte, Table 1, 1907.

123. Zopf, W. Studies of Fungi in relation to their metabolic products. Botany notebook. Zentralblatt, Vol. 1, No. 14, 1903.

Translated for National Aeronatics and Space Administration under contract No. NASw 2483, by SCITRAN, P.O. Box 5456, Santa Barbara, California, 93108.